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The Use of Sand Fences in Barrier Island Restoration: Experience on the Louisiana Coast

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PURPOSE: This System-Wide Water Resources (SWWRP) technical note describes experiences with sand fences to reduce losses by wind-blown sand transport on restored barrier islands in Louisiana. Seven installations of sand fences with various plan view orientations and cross-sectional designs are reviewed. Recommendations are given for use of sand fences in conjunction with restoration of barrier island systems.

DESCRIPTION: Sand fences are porous barriers that reduce wind speed along the coast such that sand being transported by the wind accumulates on the downwind (lee) side of the fence (United Nations Environmental Programme (UNEP) 1998). Sand fences are effective where there is sufficient wind speed to transport sand at the site and a sufficient supply of nonsaturated,[1] unvegetated sand. Semipermeable sand fences can promote deposition of windblown sand, create dune features, reduce trampling of existing dunes, and protect existing or transplanted vegetation. Fences can also be combined with other management schemes such as dune walkovers and boardwalks to promote dune stabilization and reduce environmental damages (Scottish Natural Heritage 2000).

MOTIVATION: Sand fences are a low-cost method for retaining sand within a barrier island system. Newly restored or existing beaches with an abundance of nonsaturated, unvegetated sand can lose a portion of this material due to windblown, or eolian, transport of sand from the subaerial beach. Sand fences reduce local wind speed and allow eolian sediment to deposit to the lee of the fence, thus initiating formation of a dune. Fences can also determine the location of accumulation. Once a dune begins to form, this morphologic feature can be vegetated (either naturally or through planting) and can provide a significant buffer to wave forcing and reduce overtopping of the back barrier beach, as well as provide a source of sand for the barrier island during future storms.

POTENTIAL FOR EOLIAN TRANSPORT: For sand fences to initiate dune formation, three criteria are required:

1. A sufficient supply of sand that can be readily mobilized must be available for eolian transport, i.e., sand must be relatively unvegetated, nonsaturated, and unobstructed.

[1] If wind speed exceeds the critical threshold, wet sand can be transported on most beaches. Exceptions to this statement occur for beaches composed of mixed sediments (silt, clay, and sand) because the sand adheres with the finer sediments when wet, thereby forming a surface crust that is less mobile, and when a sand or mixed sediment beach is fully saturated (i.e., under water).

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2. The wind must exceed a threshold speed for the beach sand size, during nonsaturated conditions, for a sufficient duration to transport sand at a rate such that a dune can form.
3. Beach elevation must be sufficient to limit wave attack, overwash, and inundation of the sand fences and newly-forming dune.

Criteria 1 and 3 are typically met for newly-constructed beach nourishment projects. To determine whether criterion 2 is met, wind and precipitation data for the site of interest should be analyzed to determine the percentage of time wind speed exceeds a critical velocity for the sand size available on the beach, for conditions during which the beach is not saturated. Wider beaches will have more eolian transport than narrower beaches (*Coastal Engineering Manual* 2002).

The *Coastal Engineering Manual* (2002) presents a formula for the threshold wind speed that will initiate transport of nonsaturated sand (Bagnold 1941):

$$u_{*t} = A_t \sqrt{\frac{(\rho_s - \rho_a) g D_{50}}{\rho_a}} \tag{1}$$

in which ρ_s = mass density of the sediment = 2.65 g/cm^3 (quartz sand), ρ_a = mass density of air, equal to 0.001226 g/cm^3, g = acceleration of gravity, D_{50} = the mean sand grain diameter, and A_t = dimensionless coefficient equal to 0.118. The calculated threshold wind speed must be adjusted to the elevation of the wind speed measurements, and then those wind measurements exceeding this value can be used to calculate the rate of eolian transport. The *Coastal Engineering Manual* (2002) presents a method to adjust wind speeds to different elevations.

To calculate the rate of eolian transport, the *Coastal Engineering Manual* (2002) recommends a simple relationship from Hsu (1986) that has good correlation with field and lab data:

$$q = K \left[\frac{u_*}{\sqrt{g D_{50}}} \right]^3 \tag{2}$$

where q = sand transport rate in g/cm-sec, K = a dimensional eolian sand transport coefficient, and u_* = the shear velocity for those winds exceeding the threshold speed, which can be calculated for nonsaturated beaches as,

$$u_* = 0.044 U_{2m} \tag{3}$$

in which U_{2m} = average wind speed exceeding the threshold speed at the 2-m height. The eolian transport coefficient K is correlated to field and laboratory data as,

$$K = e^{-9.63 + 4.91 D_{50}} \tag{4}$$

where K is in g/cm-sec and D_{50} is in mm. Thus, with measured wind speed at the site of interest, the magnitude of potential eolian transport can be calculated with Equations 1-4. The *Coastal Engineering Manual* (2002) presents an example for this type of calculation (Example III-4-4, p. III-4-22).

MATERIALS: Almost any kind of fence can function as a sand fence provided the structure reduces the wind speed, but does not completely block the wind (UNEP 1998). Thus, neither a completely solid fence such as plastic sheeting nor open fences such as chicken wire will function satisfactorily as a sand fence (*Shore Protection Manual* 1984). Typical sand fences consist of vertical wooden slats joined with wire (Figures 1 and 2) or wooden pallets wired together and supported with fence posts. Construction and installation of sand fences are relatively inexpensive, and fences have proven effective in building dunes (*Shore Protection Manual* 1984).

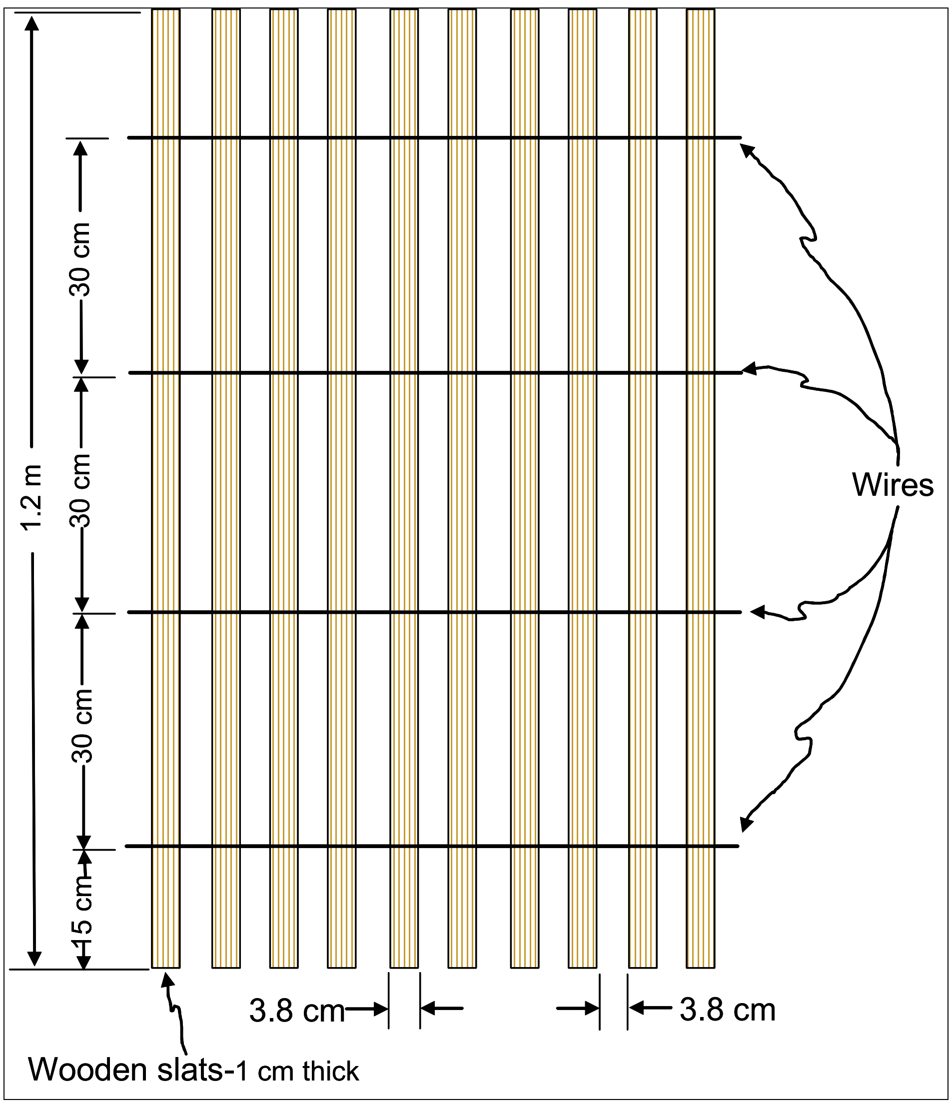

Figure 1. Schematic diagram of typical sand fence design (after Woodhouse 1978).

Figure 2. Sand fence nearly 3 years after installation; shrinkage and breaking of wooden slats have increased porosity through time.

Sand fences of various types have been constructed for centuries to control wind erosion and promote dune formation. Fence materials have included chestnut palings, brushwood, wooden slats, and synthetic fabrics (Savage and Woodhouse 1969). Other materials have been emplaced to trap sand, such as branches or young trees placed flat on the ground. Some sites have had collected windblown sand with discarded Christmas trees as sand-trapping fences and have had some success, especially where they were placed to repair the damage caused by vehicles driving over dunes.

The choice of materials for fences will depend on required life, length of frontage, commitment to maintenance, and the potential for vandalism. Brushwood is normally the cheapest material. Synthetics vary from low-cost materials such as strawberry netting up to expensive polypropylene, nylon, or composite wire/synthetic webs. Life expectancies of synthetics vary from 1 year to decades, and maintenance is minimal. Chestnut paling fence is commonly used for dune management in England as it is widely available, easy to erect and has a life expectancy of 2-5 years (Scottish Natural Heritage 2000). In Louisiana, fences constructed of wooden slats woven together with wire, similar to snow fences, are common (Figure 2). Sand fencing can be ordered commercially and to specifications if there are special needs.

DESIGN AND PLACEMENT: The space between the slats allows the sand-laden wind to blow through, but reduces the velocity sufficiently such that the entrained sand is deposited on the lee of the fence. This space between slats is an element of porosity. Porosity is defined as the void to

solid ratio and plays a vital role in the efficacy of sand fences (Savage and Woodhouse 1969; Manohar and Bruun 1970; Hotta et al. 1987). The most effective porosity is approximately 50 percent or less, commonly available in many commercial slat fences. For wooden slat fences, the slats should be not more than 50 mm wide with gaps of the same size. Wider slats will promote local scour rather than deposition, and wider gaps will reduce efficiency in causing deposition. Manohar and Bruun (1970) and Hotta et al. (1987) have observed that a slat width of 3.8 cm is most effective.

Fences can be installed forward of the toe of the dune where they will be subject to occasional wave attack during storms. Low-cost biodegradable fence material, such as brushwood, can be considered expendable during extreme storms, but the posts and tensioning wires are best set up to last for several years as they are costly to replace. Posts should be long enough to allow burial to about 1 m below the lowest expected beach level. The approximate limits of wave run-up can be established by observing and recording the location of the strand line over spring tide periods during both winter storms and more normal wave conditions (Scottish Natural Heritage 2000).

Vegetative planting should be undertaken after fences are placed, rather than before, to reduce trampling and to take advantage of sand accumulated by the fences. Successful sand fences may be buried within several seasons and a new line of fences can be added to continue sand deposition (Hotta et al. 1991). Fences can be built at any time of year, but associated transplanting is best completed in the spring (Scottish Natural Heritage 2000).

The placement of sand fences on the upper beach and within dune gaps has an effect on wind-blown sand similar to that of natural vegetation. Because fences create a partial obstruction to airflow, the wind velocity decreases, causing some of the entrained sand to fall from suspension and to gradually accumulate on their downwind (lee) side. Similarly, the planting of vegetation accomplishes sand accumulation in a natural way, but is much slower and more labor intensive than sand fences (Morgan and Stone 1987).

LOUISIANA EXPERIENCE WITH SAND FENCES

Barrier Island Restoration. Much of coastal Louisiana is eroding and the loss of environmentally sensitive lands requires remediation if this trend is to be mitigated (Boesch et al. 1994; Khalil et al. 2006). Barrier islands are the first line of defense in protecting coastal wetlands and communities from devastating tropical storms. They are also critical in maintaining salinity gradients that are vital for proper functioning of the estuarine systems behind them, including coastal wetlands. Thus, continued erosion of the barrier islands and headlands compromises the natural protective functions to maintain the adjacent mainland marshes and wetlands from the effects of storm surge, saltwater intrusion, increased tidal prism and energetic storm waves (McBride and Byrnes 1997).

Recent multiple tropical weather systems (Hurricane Ivan in 2004, Hurricanes Dennis, Katrina, and Rita in 2005) have exacerbated the degradation of mainland gulf shorelines and delta-front barrier islands in Louisiana (Boesch 2005). The barrier islands and wetlands have recently been restored to stabilize landward retreat and restore habitat (Khalil et al. 2006). Amelioration of shoreline retreat and submergence of barrier and deltaic systems can be achieved through

soft nonstructural engineering efforts or involving placement of dredged sediment to rehabilitate degraded beaches, dunes, and marshes. These islands are further stabilized by installing sand fences and facilitating vegetative growth on dunes and in marshes to protect the bayside beaches.

Overview of Restoration Projects. Restoration of barrier islands in Louisiana depends on the placement of sand from a source outside the present-day transport system. Sand is a valuable commodity in coastal Louisiana as most of the sediment in the deltaic regime is muddy mixed clay, silt, and mud (Khalil et al. 2006). Dredged sand is placed to restore the gulfside sandy shores of barrier islands. Once the sand is placed, eolian, wave, and tidal actions can transport it out of the project area. Sand fences can conserve sand and maintain and build dunes (Khalil et al. 2006).

The total cost of installation of sand fences is approximately 1 percent of the total cost of barrier island restoration (approximately $36/lin m). To effectively utilize fences, eolian transport processes and precipitation data for the site must be understood to conserve and redistribute the sand in a linear fashion to create dunes. Thus, the primary purpose of a sand fence is to stabilize portions of the bare beach and overwash areas on a barrier island. A secondary purpose is to increase the elevation of areas by accumulating sand to create foredunes behind the fences.

Since 1995, sand fences have been installed in conjunction with barrier island restoration projects (Figure 3): Timbalier Island (TE-18), East Island (TE-20), Trinity Island (TE-24), Whiskey Island (TE-27), East Timbalier Island (TE 25 & 30) and Timbalier Island's second installation (TE-40). The Isle Dernieres barrier islands (East Island, Trinity Island, Whiskey Island, Wine Island, and Raccoon Island) are presently experiencing some of the highest rates of erosion of any coastal region in the world. Between 1887 and 1988, the average annual rate of land loss was 28.2 ha/year, and the average rate of gulf shoreline retreat was 11.1 m/year (McBride et al. 1991). Disintegration of this barrier system has decreased the natural protective capacity to maintain the adjacent mainland marshes and wetlands from the effects of storm surge, saltwater intrusion, increased tidal prism, and energetic storm waves (McBride and Byrnes 1997). To protect and mitigate the accelerated land loss along the fringing mainland marshes, Whiskey, Trinity and East Islands were simultaneously restored in 1998. The specific goals of the projects were to increase the height and width of the islands by placement of dredged sediment and to reduce the loss of dredged sediment through sand fences and subsequent planting (Khalil and Lee 2004).

The sand fences were installed immediately after construction on Trinity and East Islands, whereas on Whiskey Island, fences were installed almost a year and a half after restoration. Evidence of eolian transport along the fill surface during the first 6 months following construction could be observed on Trinity and East Islands. The fences trapped eolian transport of sand (which otherwise would have blown away) and initiated the formation of foredunes.

However, not all the sand fences were successful in conserving sand on the barrier islands and creating protective dunes. Sand fences were successful at Trinity, East and Timbalier Islands (second restoration, in 2004). The reasons for failure of sand fences are discussed and how the lessons learned were incorporated into future projects.

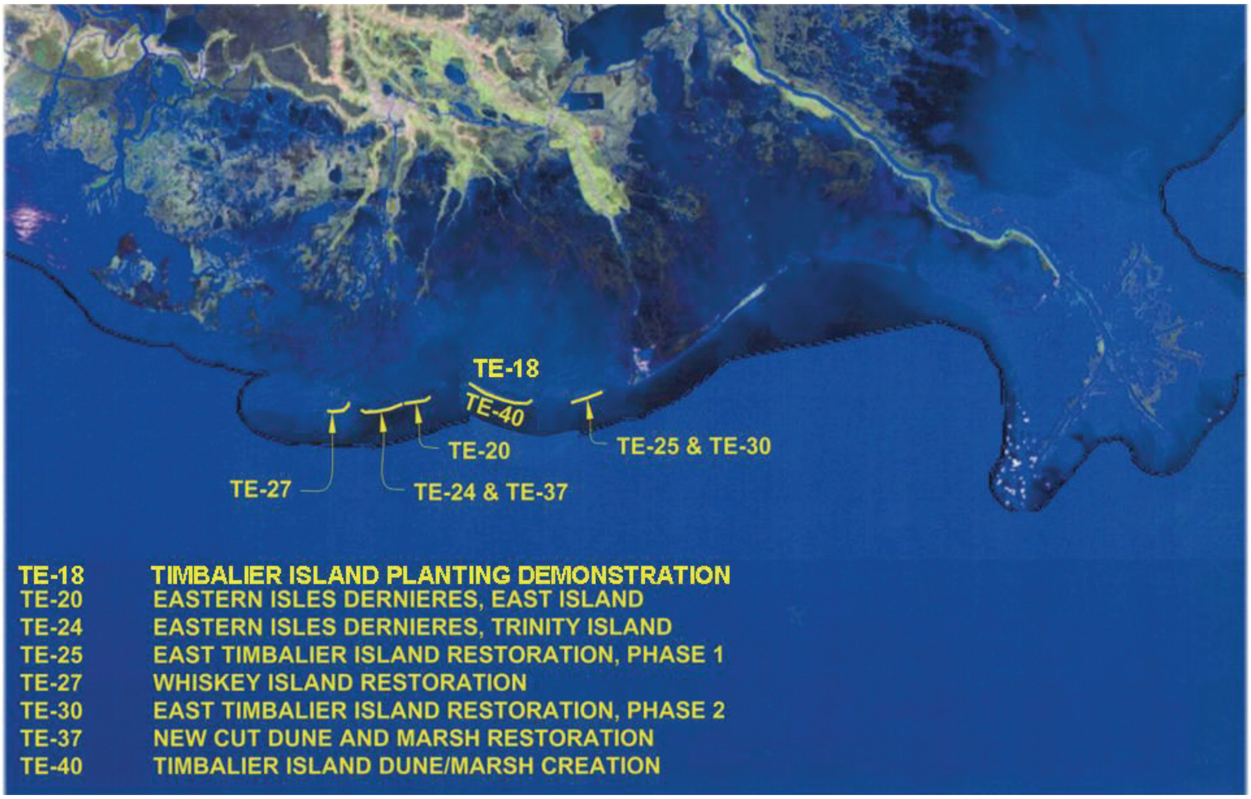

Figure 3. Location of Louisiana barrier island restoration projects and sand fence installations between 1995 and 2004.

Wind Dynamics. Wind velocity and the vertical gradient of wind speed near the ground are controlling factors in determining the viability of eolian transport and how much sand will be transported by wind. Other sediment characteristics such as size, distribution, packing, and moisture content play roles (Hsu 2002). Typical sands on Louisiana beaches, whether natural or created, have a median diameter of approximately 0.15 mm. A wind speed of 5 m/sec or more will mobilize this sand size (Hsu and Blanchard 1991).

Observations of morphology change as well as onsite experience indicate that significant eolian transport occurs for restored barrier islands. The greatest potential for eolian transport exceeding a critical wind speed of approximately 5 m/sec exists from September through May (Figure 4). This period is when cold fronts and extratropical cyclones are most frequent along the northern Gulf of Mexico.

The greatest percentages of hourly wind observations exceeding 5 m/sec for a 5-year wind record at Grand Isle, LA, are from the north-northeast (Figure 5). However, the duration of time the beach is saturated, which is a factor of monthly precipitation (Figure 6) and site-specific elevation at the project site, must be evaluated simultaneously to determine the potential for eolian transport. For a beach that drains sufficiently during and following precipitation events, it is most likely that eolian transport of sand in this area of Louisiana will be directed from the subaerial beach offshore to deposit in the gulf, rather than shoreward to deposit in the bay or estuary.

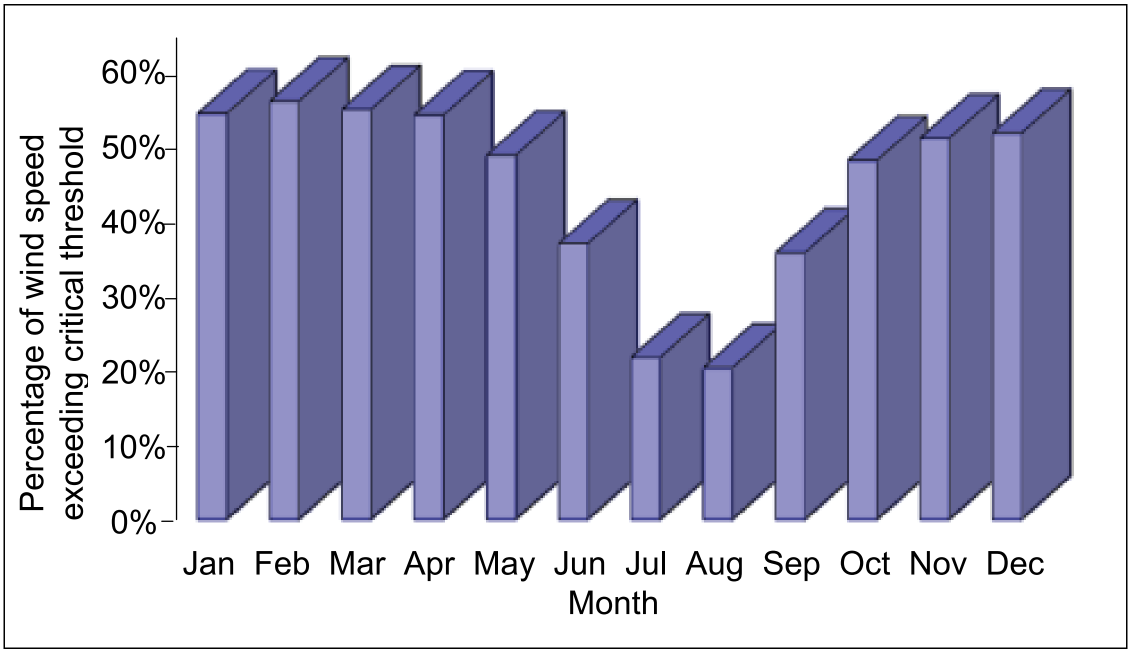

Figure 4. Percentage of average wind speed measurements that exceed critical threshold (5 m/sec for 0.15-mm sand) in southern Louisiana.

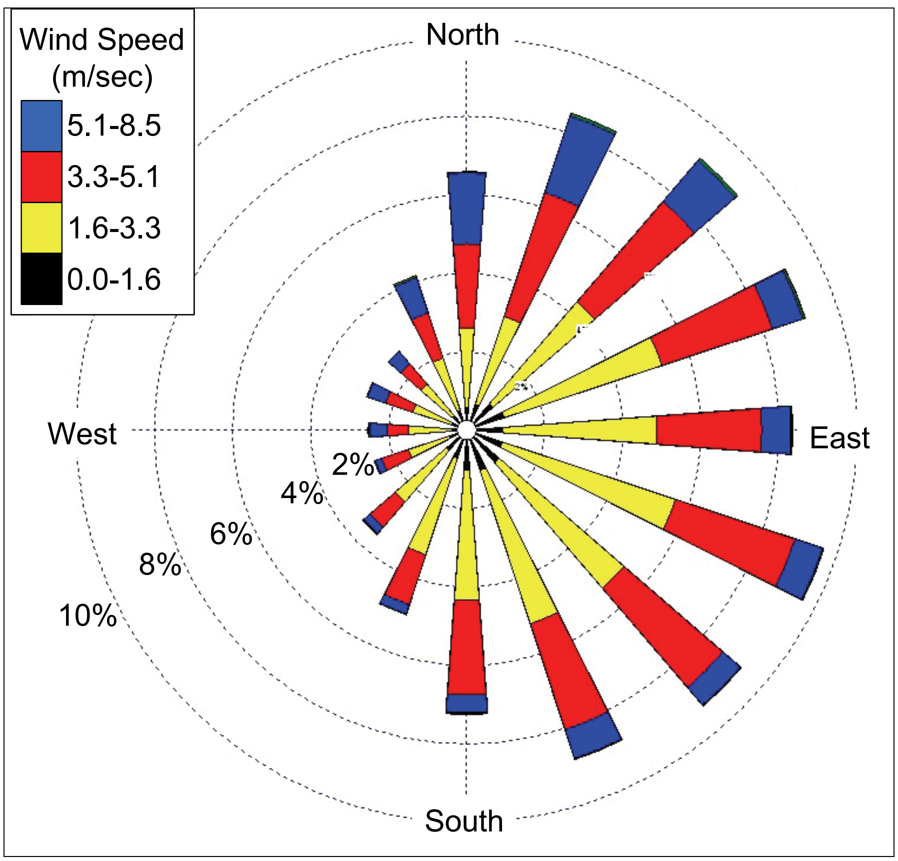

Figure 5. Winds of sufficient speed for eolian transport of 0.15-mm sand in Louisiana (exceeding 5 m/sec, noted by blue bars) are primarily from north/northeast.

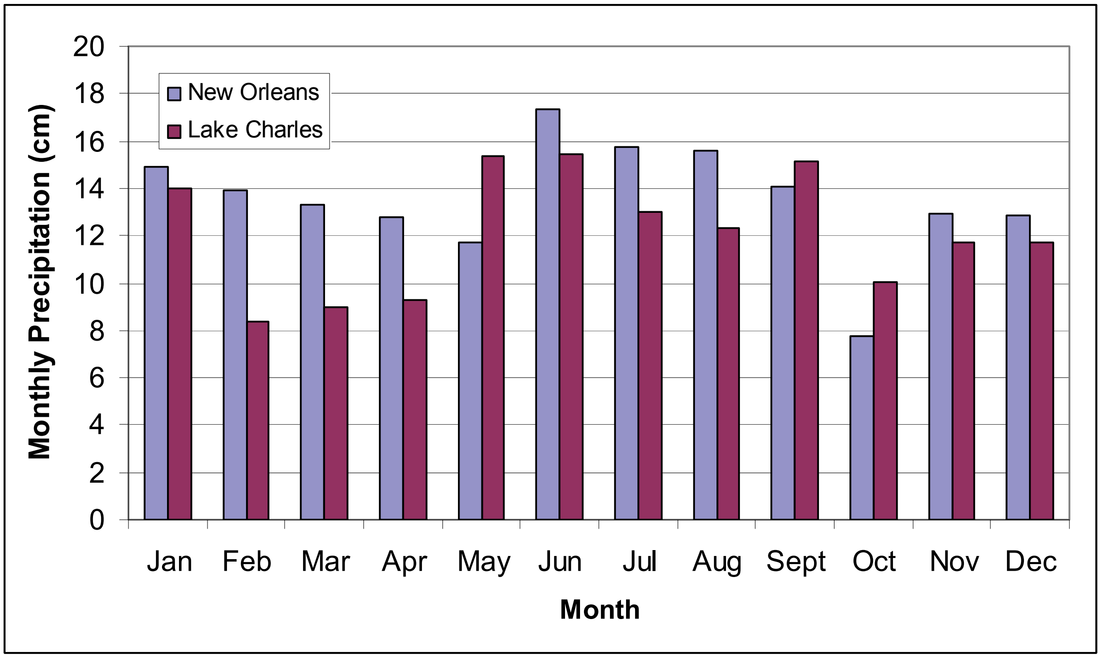

Figure 6. Average monthly precipitation for two locations in Louisiana.

Timbalier Island Plantings Demonstration (TE-18). The first sand fence in Louisiana was installed on the western side of Timbalier Island during the Timbalier Island Plantings Demonstration Project. This project was initiated in May 1995 and consisted of fences with vegetative plantings. Project goals were to be accomplished by the construction of approximately 2,300 m of sand fences at seven sites along the length of the island (Lee et al. 2006). Each site had a primary fence oriented parallel to the gulf shoreline with perpendicular spurs every 15.2 m that extended 7.6 m bayward from the primary fence (Figures 7 and 8). Fence construction was completed in July 1995. Numerous tropical storms impacted the fences, and repairs were conducted in October 1995 to sections A through D (see Figure 7 for locations). Fence sections E, I-1, and I -2 were damaged beyond repair and abandoned. Fence sections B through D were repaired again in July 1996 immediately prior to planting due to additional storm damage (Lee et al. 2006).

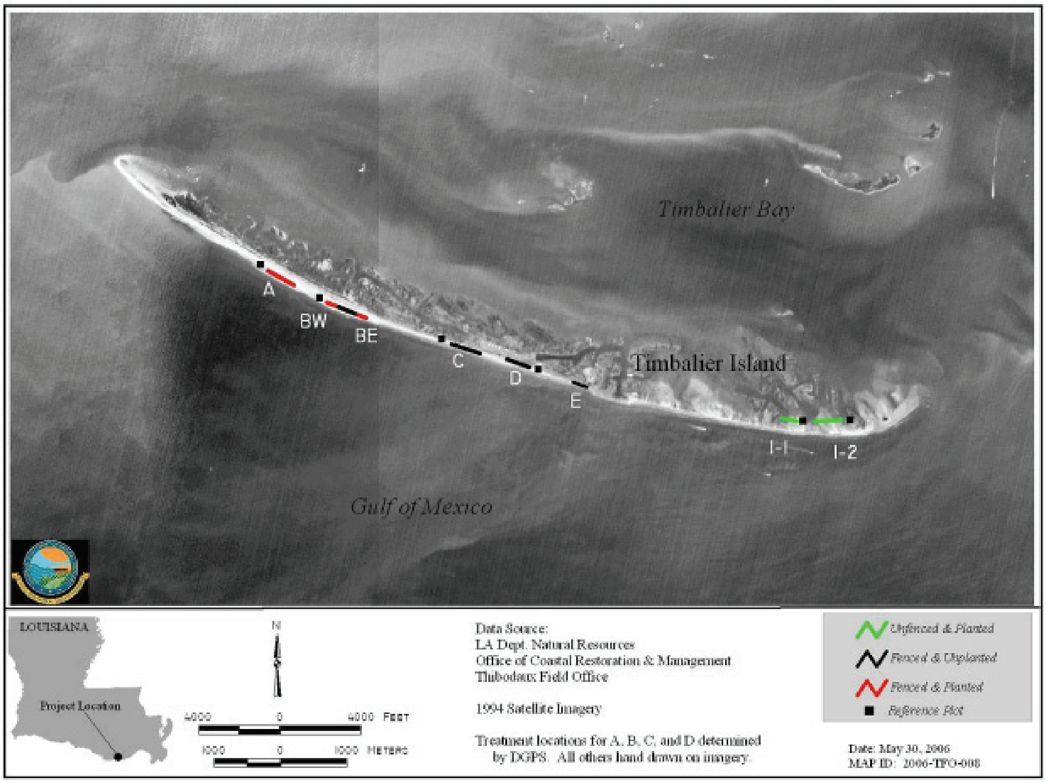

Figure 7. Timbalier Island Plantings Demonstration project features.

Figure 8. Sand fences (parallel to gulf shoreline) with perpendicular spurs (extending towards bay) at Timbalier Island Plantings Demonstration Project (Site A July 1996, looking northwest).

The specific goals of the project were to increase the elevation of areas enclosed by the fences and to increase the percent cover of emergent vegetation behind them. To evaluate meeting these goals, aerial photography, surveys, and vegetation sampling were conducted to determine changes in habitat, acreage, elevation, volume, and vegetation cover and composition. The sand fences and plantings created dunes (Lee et al. 2006). These results indicated that initial filling of the fences was rapid, followed by a decline in sand accumulation. However, a decrease in the accumulation rates in the reference (nonfenced) areas seemed to indicate other factors were involved, such as reduced sand availability and shore erosion. Townson et al. (2000) reported much lower volume accumulations per linear meter of beach for this project than had been measured in previous studies for other parts of the country (Savage and Woodhouse 1969; Dahl et al. 1975; Myer and Chester 1977; Woodhouse et al. 1976; Knutson 1980). However, all but one site experienced erosion throughout the project life. Dunes grew in elevation at an annual rate of 12.2 cm/year, whereas associated nonfenced reference plots grew at an average rate of 9.1 cm/year over the 5-year period (Lee et al. 2006). Even well established dunes could not prevent the natural transgression of the shoreline that eventually eroded as the shoreline receded landward. This is evidenced by the fact that all treatments, other than site A, eroded from east to west, as the barrier island's natural process of northwestward migration occurred. One-time applications of fences and plantings cannot stabilize the beach, which will continue to exhibit similar migrational behavior on Louisiana's highly transgressive shorelines.

Based on observations at this site, Mendelssohn and Hester (1988) reported that sand fences with spurs accumulated more sand during the first year of construction compared to other designs tested. However, after 3 years, a straight fence design collected approximately 160 percent more sand than the fence with spurs (Mendelssohn and Hester 1988).

East Island (TE-20) and Trinity Island (TE-24). East, Trinity, and Whiskey Islands were restored simultaneously by placing approximately 3 million cu m of dredged sediment. The Whiskey Island restoration is discussed in the next section. On East Island, the design template consisted of a 2.4-m high dune crest with a variable width ranging from 91.5 to150 m (Khalil and Lee 2004). Approximately 5,400 m of sand fence was installed immediately after restoration. Relatively short sand fences were installed with orientations almost diagonal to the general trend of the island (Figure 9).

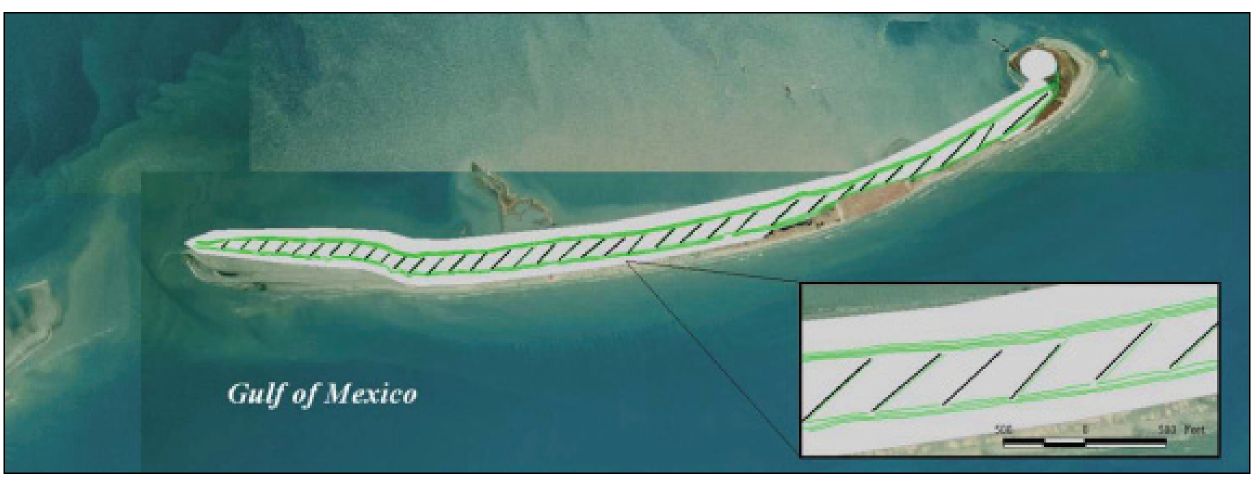

Figure 9. General orientation and pattern of sand fence (dark lines) in East Island.

These fences trapped sand to create almost NE-SW trending dunes of higher relief (1.8-2.1 m). At places these dunes attained 2.5 m in relief (Figure 10). Thus, these fences were able to trap and redistribute the sediment in their lee side to form several parallel dunes.

Figure 10. Sand fence with dune created on East Island. Dune is on southeast side of fence indicating northerly winds moving sand and depositing on southeastern side.

Formation of these dunes indicates the capability of sand fences in trapping and redistributing sand which otherwise would have been lost or eroded. LiDAR data showed an overall increase in the elevation of the island especially in the central portion where dunes were built by the fences (Figure 11).

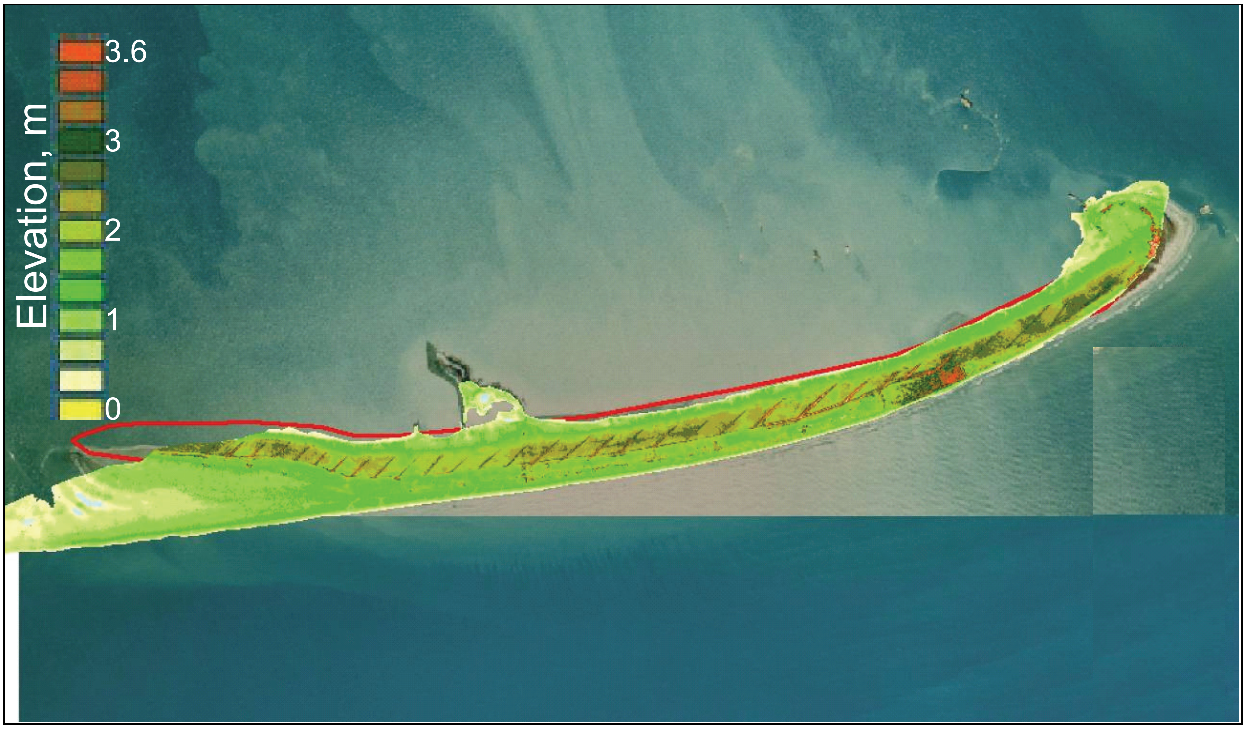

Figure 11. LiDAR photograph indicating general elevation in East Island. Note central elevated portion with diagonal sand fences.

However, because the orientation of the sand fences was diagonal to the trend of the shoreline, the dunes formed in a morphology that tended to funnel water and create scour on the beach during overwash (Khalil and Lee 2004) (Figure 12).

Figure 12. Scour between two dunes at East Island indicates focusing of water due to orientation of dunes.

The funneling phenomenon is depicted in Figure 13, which shows the movement of water attributed to overwash. The overwash was focused between the dunes, resulting in scouring.

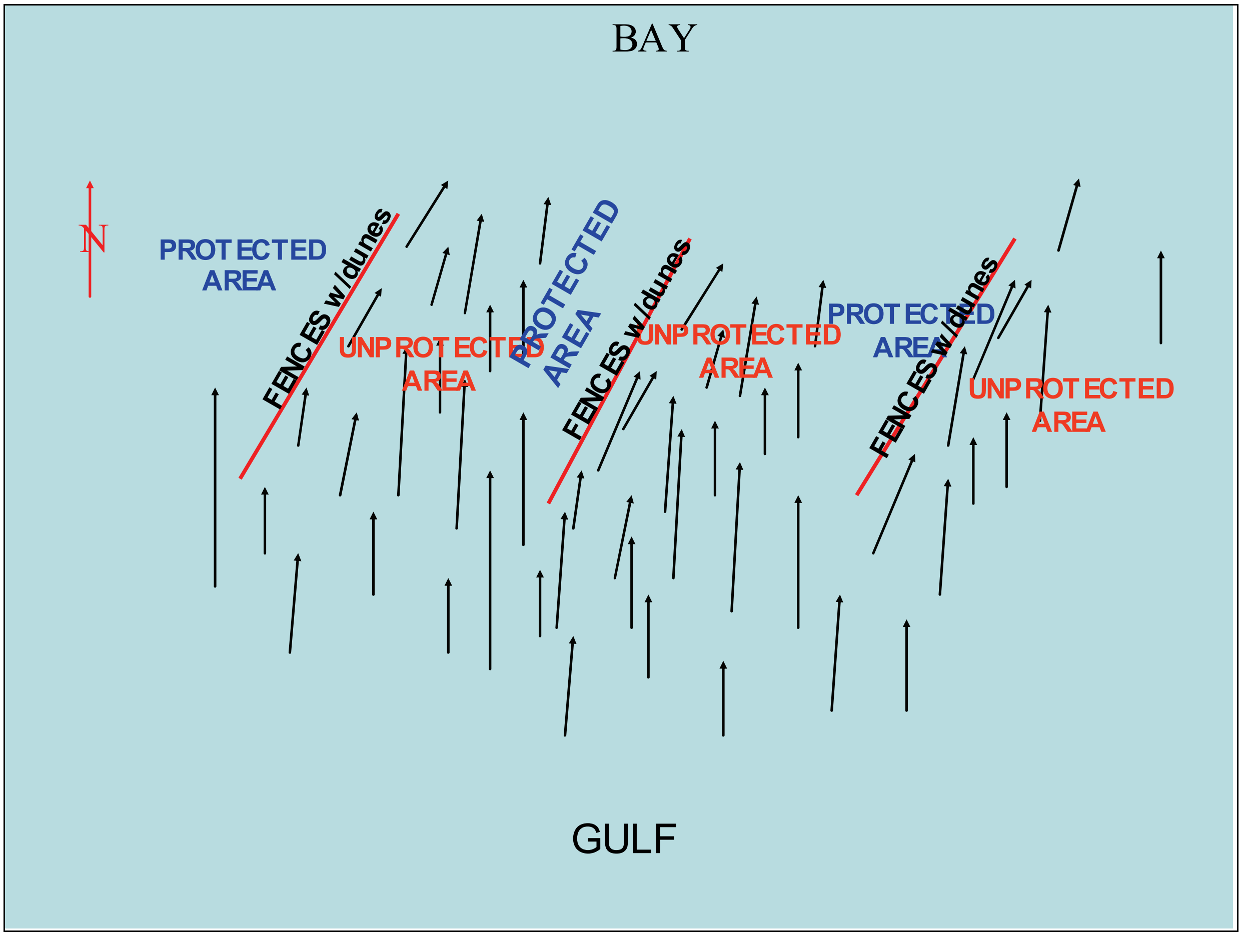

Figure 13. Schematic diagram depicting overwash and resulting scour between diagonal dunes.

A similar phenomenon occurred on Trinity Island. The diagonal orientation of the sand fences and, ultimately, the dunes that formed funneled water in-between these relatively high-relief morphologic forms, created scour on the subaerial beach (Figure 14). In addition, dunes in this diagonal alignment will not function as levees to backshore areas nor will they provide a source of sediment for the foreshore.

Figure 14. Looking south on Trinity Island (note scour at rear of fence spur indicating focusing of water during overwash).

Whiskey Island Restoration (TE-27). Whiskey Island was restored concurrently with Trinity and East Islands in 1998 by placing approximately 2.2 million cu m of dredged sediment and building 1.2-m high dunes. Note that the elevation of the Whiskey Island dunes was lower than the 2.4-m-high dunes that were initially constructed on Trinity and East Islands. Sand fences were not erected immediately after construction. These fences were installed one and a half years after restoration, but were unsuccessful at trapping sand. Lower dune elevation as compared to Trinity and East Islands may have played a role that led to lack of trapped sand.

It is likely that a substantial amount of sediment placed on the beach was transported off the island into the Gulf of Mexico or to Lake Pelto. It is difficult to attribute the ineffectiveness of sand fences entirely due to their delayed installation. Other factors such as elevation of the dune platform, orientation of the fences, and the locale of fences may also have contributed to failure in conserving sand.

East Timbalier Island (TE-25, TE-30). East Timbalier Island is approximately 6.5 km long and 0.9 km wide, and it is located at the mouth of Timbalier Bay. This island was restored in 2000 by placing approximately 2 million cu m of dredged sediment to create a 61-m-wide dune to an elevation of 1.5 m National Geodetic Vertical Datum 1929 (NGVD29) and a back-barrier marsh platform at 0.6 m NGVD29 (West et al. 2005). Shoreline rock revetment placed upon an earthen dike and sand fences with vegetative plantings were placed to stabilize the constructed dune. The sand fence was placed in a shore-parallel position with varying orientations of spurs to trap windblown sand and to aid in the development of dune habitat (Figure 15). In some areas of the island, spur fences either intersected or crossed the linear shore-parallel fence at near -45-deg

angles and resulted in fences segments that resembled an “A” or “V” alignment. Approximately 4,000 m of sand fence was installed by the end of September 2000 (West et al. 2005).

Figure 15. Location of sediment fences and vegetative plantings along East Timbalier Island, showing various orientations (A-configurations, V-configurations, and linear shore-parallel).

No sand fences were found completely intact during the inspection in 2005 (West et al. 2005). The late 2002 storms appeared to have removed the sand fences from the project area. Fill sediment had a higher percentage of fines considered too great and unsuitable as beach fill. Initially, the sand fences on the western end of the island trapped sand and built dunes on both sides of the fence. However, in the central and eastern portions of the island, sand fences were ineffective in trapping and redistributing sand.

Timbalier Island Restoration (TE-40). The eastern portion of Timbalier Island was restored during 2004 and included the construction of 110 ha of supratidal and intratidal habitat by placing approximately 2.7 million cu m of sand. The Timbalier Island design template consisted of a 2.4-m-high dune crest with width varying from 100 to 150 m. The gulf side of this dune had a crest elevation of 2.4 m with a 1:50 slope to the gulf. In the bay side, the dune had a slope of 1:10 to the marsh platform which varied in height from 0.6 to 1.6 m.

After observing the efficacy of sand fences on the Isle Dernieres projects, two rows of shore-parallel straight sand fences totaling approximately 10,600 m were installed immediately after the restoration of the island. These rows were 30 m apart. The fences trapped sand and built extensive dunes within a few months after their installation (Figure 16). The fences were installed in December 2004 and by April 2005 a dune higher than the fence had formed around the northern fence. The northern sand fence had accumulated more sand than the southern fence. Sand dunes were built on the lee (south) side of this northern fence, indicating the influence of the wind from the north. Sand accumulation was so great on the north fences that at places the dunes reached >1.5 m in elevation and overtopped the fences to the extent that the fences were completely buried. The dune-base built in the lee of the north fence ranged in average around 15 m in width and 1.7 m in height with a crest width of ~4 m. Because it was buried, the northern fence was no longer capable of trapping sand. The southern fence also trapped sand, but to a lesser degree. The average height of the dune was 0.6 m, located on both sides of the fence. The

width of the base of the dune ranged from 7.5 to 9 m and the crest width averaged 3 m. Obviously, the northern fence performed better and trapped more sand.

Figure 16. Looking east, formation of dunes towards south of northern sand fence at Timbalier Island.

It appears that the southern fence could not perform well because of the presence of northern fence. The sediment supply for the southern fence from the north was restricted by the presence of the northern sand fence and dunes that formed. This reaffirms the conclusion that wind capable of transporting sand on Louisiana islands during nonsaturated conditions is from north to south (or northeast to southwest).

Because of the difference in elevation of the two adjacent dunes, rainwater accumulated within the trough of the two dunes and flowed gulfward, towards the southern dune, which was lower in elevation. This flow created three breaches in the southern dune as well on the beach-berm (Figure 17). If the sand fences had instead been installed sequentially, then the development of a swale between dunes could have been avoided. Sequencing of fences is necessary if more than one sand fence will be installed. The distance between rows of fencing should not exceed more than four times the height of the fence (Savage 1963), which in this case would be 4.8 m. For Louisiana, fences should be installed in sequence starting from gulf side to build larger foredunes on the gulf side of the island.

Figure 17. Rainwater that accumulated between dunes flowed towards gulf through southern dunes, which was lower in elevation, creating breaching in dune and on beach berm (looking north).

DISCUSSION: Sand fences have the capability to conserve sand within the project area for nourished beaches. Sand fences installed immediately after construction can capture sand, create dunes, and reduce eolian erosion. At Whiskey Island, the fences were installed almost a year and a half later. This absence of sand fences during the post-construction adjustment period (along with lower general elevation) may have reduced project longevity. The immediate post-construction adjustment through eolian erosion in absence of any fence may have reduced the barrier island's elevation and increased the frequency of overwash. Thus, the timing of installation of sand fences is critical. Ideally, sand fences should be installed immediately after placement of dredged sand.

Sand fences were installed in various alignments in all these projects. For most of Trinity Island, the fences were aligned in zigzag fashion with an overall shore-parallel trend, resulting in formation of shore parallel dunes. On East Island, fences and the resulting dunes were diagonal to the general trend of the island. To trap and redistribute sand in form of shore-parallel dunes, which could act both as a barrier and a reservoir of sand during storm occurrence, it is recommended that sand fences be installed parallel to the shoreline or to the general trend of the island. It was also seen in Trinity Island that the zigzag alignment of sand fences did not make any difference, except that the increase in fence length increased the cost of the installation. Thus, the cost-effective construction method is to install straight shore-parallel sand fences.

Any gap in the sand fence results in a discontinuity in the dune feature. The absence of a dune promotes funneling of overwash and results in scour during overwash. Thus, the fence should be continuous (without gaps). If access is needed, then the gap should either be minimum or staggered.

Valuable lessons were learned from the installation and subsequent monitoring of the performance of these fences (Khalil and Lee 2004). Some of these lessons were applied during the installation of sand fences in Timbalier Island, which was restored in late 2004. Since then, some more lessons were learned especially in sequencing of installation or installation of sand fences in phases. On the basis of these lessons, several recommendations can be made for future installation of sand fences.

CONCLUSIONS AND RECOMMENDATIONS: Sand fences are an inexpensive way of conserving sand following construction of beach nourishment and barrier restoration projects, provided they are installed in appropriate and timely manner (Knotts et al. 2006). Sand fences with different alignments were installed on several barrier islands in Louisiana. An analysis of wind data from Grand Isle indicates that wind exceeds the critical threshold velocity for eolian transport more than 50 percent of the year (assuming a mean grain size of 0.15 mm). This means that the potential for sediment transport along a nonsaturated, unvegetated surface exists for a significant period of time. Areas that are not fenced or which experience delay in the completion of dredging and fence installation may experience a significant deflation of the newly restored surfaces (Knotts et al. 2006). During this time, large quantities of sediment may be transported into the nearshore surf, reworked offshore or downdrift and into the adjacent inlets, thereby effectively lost from the barrier island system (Armbruster et al. 1999).

The orientation of sand fences should maximize the retention of sand and its linear formation as shore-parallel dunes. If a sand fence is placed in a configuration that is not shore parallel, dunes that are formed will not be shore parallel, thus increasing the possibility of wave focusing and subsequent scour of the dune platform during storms. On the basis of observation of performance of sand fences on various barrier islands (Khalil and Lee 2004), it is recommended that the alignment of sand fences be shore parallel to maximize the stability of the dune platform during storms.

Multiple rows of sand fences should be installed in phases, and installation should commence from the downwind side of the island (gulf side for Louisiana). Initial void ratio of the fences should be about 50 percent or less. Biodegradable wooden poles should be used instead of iron poles. Phased multispecies vegetation planting after dune formation will promote dune stabilization.

On the basis of observations of performances of sand fences in Timbalier Island (1995), Whiskey Island (1998), Trinity Island (1998), East Island (1998), East Timbalier (2000), and again at Timbalier Island (2004), and review of literature (Hotta et al. 1987, 1991; Scottish National Heritage 2000), the following recommendations are made:

1. Timing of installation: Sand fences should be installed immediately after construction of beach nourishment and barrier island restoration projects.

2. Orientation of the sand fences: Fences should be installed parallel to the shoreline or along the general trend of the restored island.
3. Linear fences: Linear sand fences are as effective as zigzag alignment and cost less per linear foot (Savage 1963). Spurs do not aid in conserving sand.
4. Gaps: The fences should have minimal gaps such that a continuous dune is created. Any gaps required for access purposes should be kept at minimum, and fences can be overlapped at access gaps to maintain integrity of the dune.
5. Slat width: Manohar and Bruun (1970) and Hotta et al. (1987) found that a slat width of 3.8 cm was most effective.
6. Fence porosity: The most effective porosity (void to solid ratio) is 50 percent or less (Savage and Woodhouse 1969; Manohar and Bruun 1970; Hotta et al. 1987).
7. Locale of sand fence: Sand fences should be constructed sufficiently landward from the berm crest to limit frequent wave attack.
8. Sequence of sand fence installation: If several rows of sand fences will be installed, the row furthest downwind should be installed first. Once it has filled to a desired level, another row may be constructed in the upwind direction. As observed at Timbalier Island (2004), the initial sand fence should be installed towards the gulf side and once it is filled to capacity, the subsequent rows should be installed progressively towards the north or the bay side.
9. Spacing between multiple rows of sand fences: Savage and Woodhouse (1969) recommended that the most effective distance between two rows of fences is four times the height of fence. By installing succeeding fences parallel to and at a spacing of about four times the height of the fence, the dune width can be increased. Two rows of sand fences at a spacing of four times the height (~4.9 m) are being installed at the New Cut restoration project (see Figure 3) planned for 2007-2008.
10. Vegetative plantings: Once dunes are created, they are best stabilized with vegetative planting. Vegetation will promote dune growth and enhance the beach environment. Fences without transplanting will have a short-term impact because any accumulated sand will remain unstable unless it rapidly becomes vegetated.
11. Biodegradable materials: Fences should be constructed with wooden poles, wooden slats, and other biodegradable material to ensure that any loss of the sand fence system during storms will not have adverse environmental consequences nor become a hazard in the beach and nearshore system.
12. Each site must be considered independently, with management approaches tailored to the specific site. Reliable estimates of wind speed and direction, and of precipitation, are valuable for determining fence placement location and possibility for success.
13. A policy of “adaptive management” should be considered for all sites.
14. Both long-term “average” and short-term extreme weather and sea conditions must be considered to determine the life expectancy of any operations.
15. Regular maintenance should be undertaken to repair fences.

ADDITIONAL INFORMATION: This technical note was prepared by Syed M. Khalil, geologist, Louisiana Department of Natural Resources. Review of this technical note was provided by Dr. Douglas Sherman, Texas A&M University, and by Julie Dean Rosati, and Dr. Nicholas C. Kraus of the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. The study was conducted as an activity of the Cascade work unit of the System-Wide Water Resources Program (SWWRP), under the direction of Dr. Kraus. For information on SWWRP, please consult https://swwrp.usace.army.mil/ or contact the Program Manager, Dr. Steven L. Ashby, at Steven.L.Ashby@usace.army.mil. For information on this technical note, contact Julie Rosati at Julie.D.Rosati@usace.army.mil. This technical note should be cited as follows:

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